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(71) Applicants
Thoro-Ray Inc.
Fort Worth,
Texas,
United States of America
(72) Inventors
Mortimer E. Weiss
(74) Agents
D Young & Co.

(54) Dental X-ray apparatus

(57) Intra-oral dental X-ray apparatus for panoramic dental radiography comprises an electron gun 92 having an elongated tubular target carrier 100 extending therefrom for positioning in the patient's mouth. The carrier 100 supports an inclined target 91 for direction of an X-ray pattern towards a film 95 positioned externally of the patient's mouth. Image definition is improved by a focussing anode 37 which focuses the electron beam 93 into a sharp spot (0.05 to 0.10 mm diameter) on the target 91. The potential on focussing anode 37 is adjustable to vary the size of the spot. An X-ray transmitting ceramic (oxides of Be, Al and Si) window 101 is positioned adjacent the front face of the target. The electron beam can be magnetically deflected to change the X-ray beam direction, Figures 4 and 5.

FIG. 10.

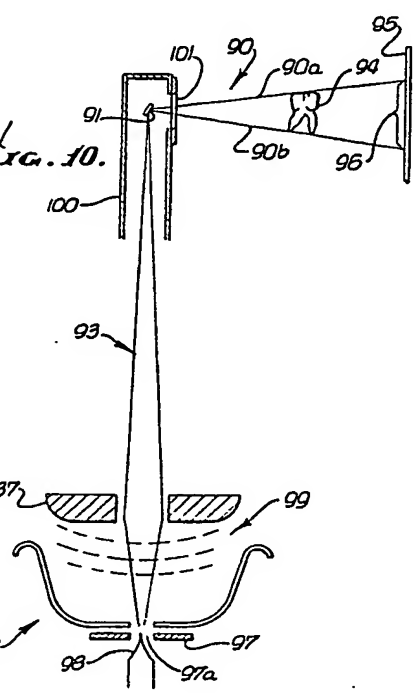

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FIG. 1.

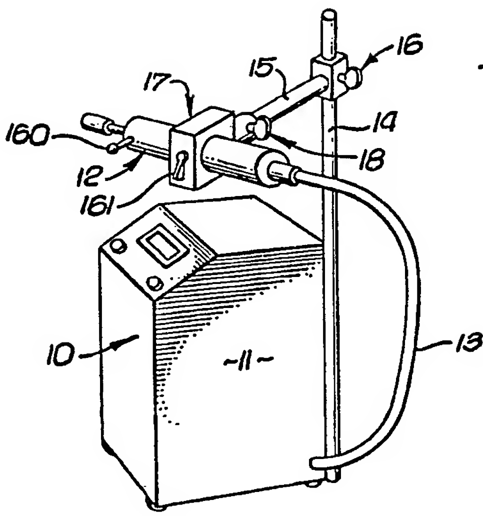

FIG. 2.

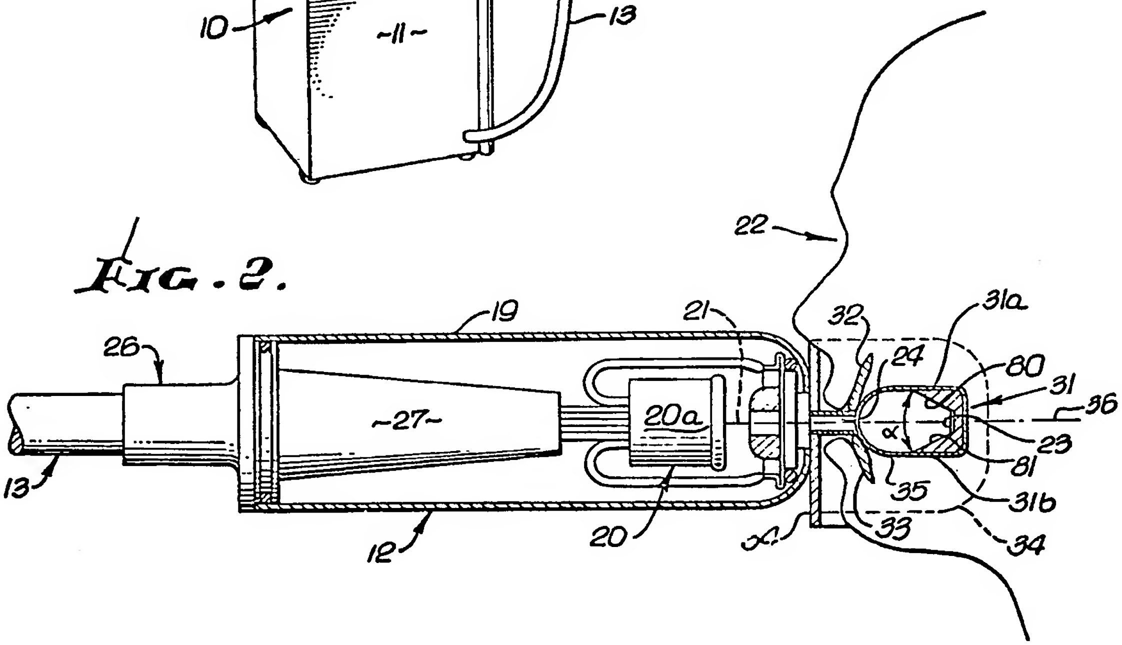

FIG. 3.

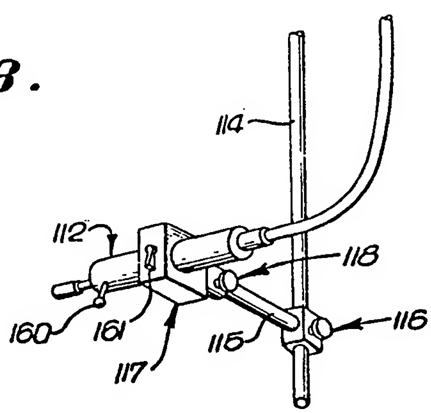

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FIG. 8.

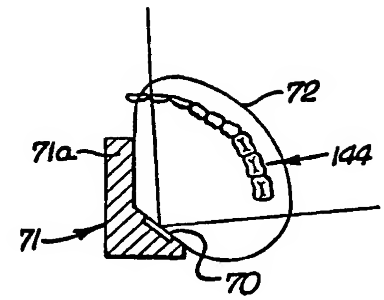


FIG. 4.

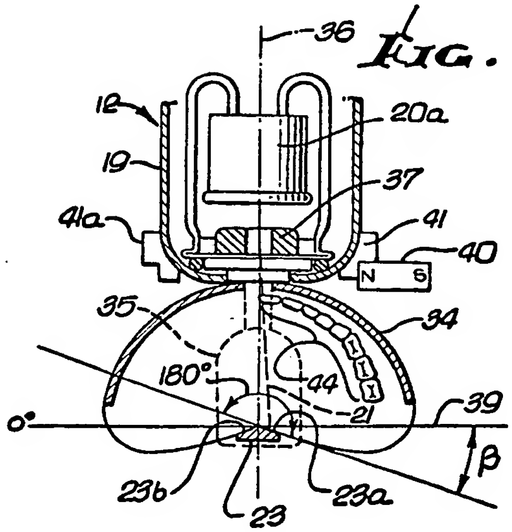


FIG. 5.

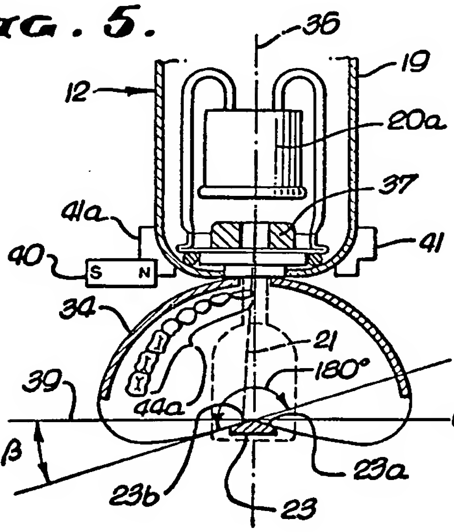


FIG. 7.

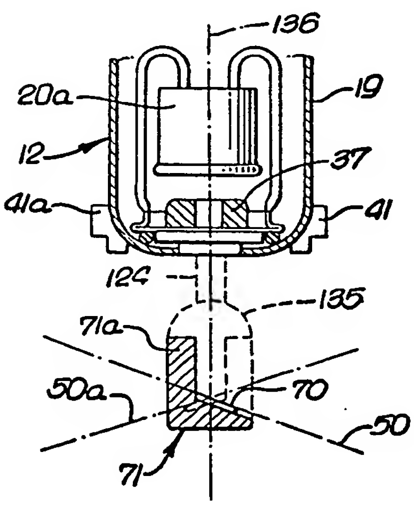


FIG. 6.

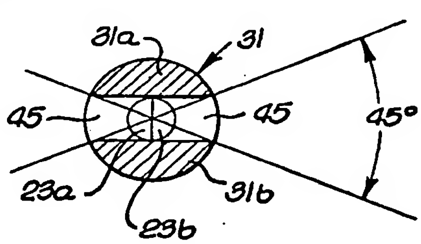


FIG. 9.

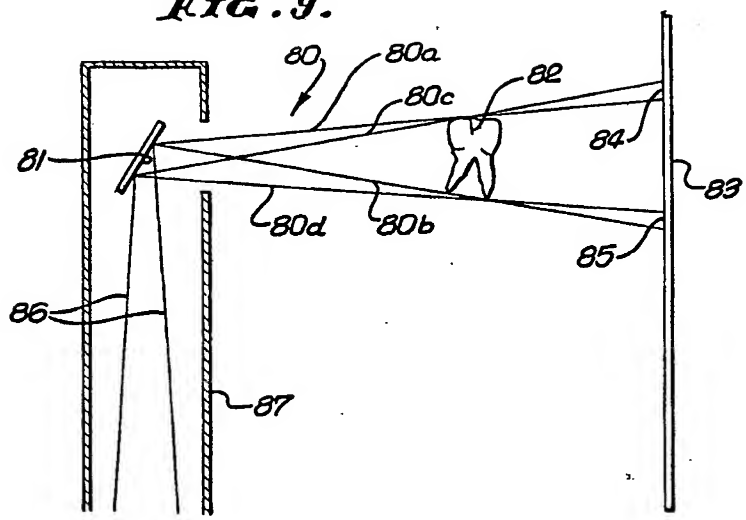


FIG. 10.

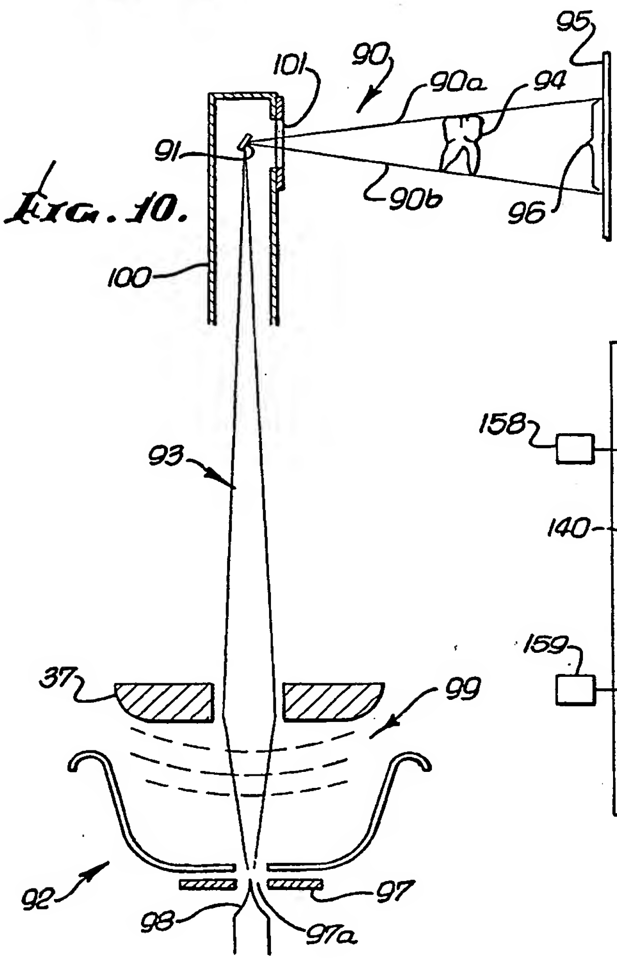
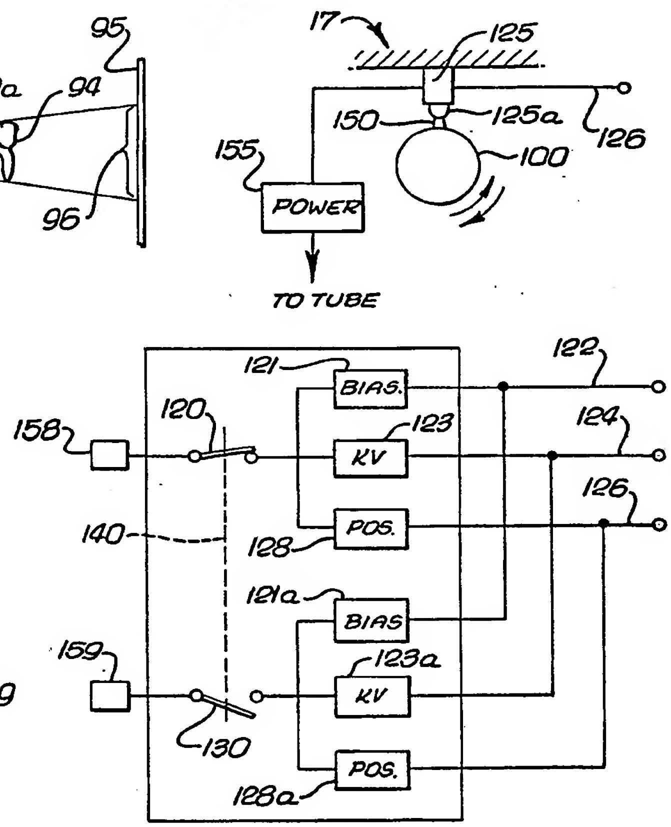


FIG. 11.



SPECIFICATION

Dental X-ray apparatus

This invention relates to dental X-ray apparatus.

Present systems of X-ray examination of human teeth require upto eighteen exposures, accompanied by objectionably excessive amounts of side radiation to sensitive areas of the brain, cortex, sinus, throat, optic and auditory nerve centres. Recently, a technique has been proposed according to which an X-ray target is introduced into the mouth, and radiation is directed from the target back through the teeth to film supported outside the mouth, thereby to produce a so-called high resolution, panoramic radiograph. One problem encountered with that type equipment concerns the tendency to produce gagging of the patient, due to the necessity of locating the target sufficiently close to the throat that back teeth will be exposed to produced X-rays. Another problem has to do with the requirement that the upper and lower teeth be alternately exposed to radiation, which in turn requires that the shield associated with the target be re-arranged. This means that the target is removed from the oral cavity after the first exposure (as for example irradiation of the upper teeth) after which the target is re-introduced to enable the second exposure (of the lower teeth) which increases the risk of gagging and otherwise discomfort the patient.

The present invention seeks to provide an improved apparatus for intra-oral use which improves image definition in panoramic dental radiographs and which provides improved patient comfort, lower X-ray exposure and protection for the upper and lower portions of the mouth and other sensitive areas of the head from unintentional X-ray exposure.

Basically, the apparatus of the present invention comprises an electron gun operable to provide an electron beam directed along an axis, a target carrier projecting from said gun along said axis and having a distal end of such a shape as to be receivable into the patient's mouth, a target carrier by said carrier at the distal end thereof in line with said axis, and at an angle thereto which is effective to produce a radiation pattern, when exposed to the electron beam, extending forwardly from said target towards the gun and laterally of the beam axis, and a shield of X-ray opaque material extending forwardly above and below said target and rearwardly thereof, said shield serving in use to restrict the radiation to a forwardly and/or laterally directed substantially wedge or cone-shaped pattern apexed on the target and delimited vertically substantially by the root tips of the upper and lower teeth, wherein said apparatus comprises means for focusing the electron beam into an impingement spot on said target.

As will be seen in the apparatus of the invention a shield projects forwardly both above and below the target to block radiation from passing to undesirable areas of the patient's head zones above the upper teeth and below the lower teeth; the shield may typically provide lateral openings to pass X-rays toward the back upper and lower teeth, the target may typically be angled rearwardly and sidewardly at one or both sides of the equipment axis so that radiation may pass through one or both of the shield side openings to provide access to the back teeth as well as front teeth; the microfocal spot is sufficiently small that the image of a tooth on X-ray film has a sharp boundary; and the radiation pattern produced by the target may be transversely shifted, as for example by sideward deflection of the beam to strike different portions of the target, or by physical rotation of the target, so that the target need not be removed from the mouth between exposures.

Preferably means are provided to vary the size of the beam impingement spot on the target for purposes as will appear hereinafter.

The invention will be further described with reference to the accompanying drawings, especially Figures 9-11 which illustrate the modifications of the present invention. Figures 1-8 are provided to aid an understanding of the subsequent figures and to illustrate various other embodiments in which the modifications of this invention can be employed. In the drawings:

Figure 1 is a perspective showing of high voltage generator equipment and X-ray tube floor mount associated with the invention;

Figure 2 is a cross-sectional view of gun and target apparatus embodying the invention;

Figure 3 is a perspective showing of an alternative X-ray tube ceiling mounting;

Figures 4 and *5* are top plan views of gun and target relationships, in schematic form;

Figure 6 is an enlarged frontal view of the target and shield;

Figure 7 is a view like Figure 4 in Figure 5, but showing an alternative target; and Figure 8 shows another target;

Figure 9 is a diagram of X-ray interception by a tooth and film;

Figure 10 is another diagram of X-ray generation at a microfocal spot on a target, and X-ray interception by a tooth and film; and Figure 11 is a circuit diagram.

Referring first to Figure 1, X-ray apparatus 10 includes a high voltage generator console 11 to which X-ray tube 12 is electrically connected, as via cable 13. A suitable adjustable support for the tube 12 includes upright post 14 carried by the console; an arm 15 adjustably attached at 16 to the post to rotate about a vertical axis; and a mount 17 for the tube apparatus and adjustably attached at 18 to the arm 15 to rotate or swivel about a horizontal axis.

Extending the description to Figure 2, the tube means 12 includes a housing 19 containing the micro-focus X-ray tube 20 which produces an electron beam 21. A beam target 23 is carried by the tube means and is located axially rearwardly thereof (relative to the patient's head 22) to be inserted or received relatively rearwardly into the patient's mouth. The forward and rearward axis appears at 36. In the example shown, the target 23 is carried by the rearward end portion of a rearwardly axially elongated tubular element 24 projecting into the patient's mouth. The cable 13 is attached to the housing at 26, and passes through an insulator 27 to the gun 20*a*. The inner conductor of the cable is at

high potential while the outer cable sheath is at ground potential and is solidly connected to the tube housing. The tube anode is also at ground potential and only the electron gun 20*a* is at high potential, insulated by gas or oil inside the tube housing. This provides the necessary electrically shock-proof mounting for intra-oral radiography.

An alternative ceiling mount for the tube 112 in Figure 3 includes an upright post 114 affixed to or carried by the ceiling of a room. Elements 115-118 correspond to elements 15-18 in Figure 1.

The target 23 may consist of tungsten embedded in a copper shield 31, the latter having upper and lower rearwardly tapering surfaces 80 and 81 which define an angle α therebetween. That angle subtends a zone which encompasses the patient's upper and lower teeth (including root areas) indicated at 32 and 33, but not including the brain or sinus area, the latter as well as the throat being protected from radiation impingement. In this regard, an X-ray film holder 34 is carried by the apparatus 12 to extend at the front of the patient's mouth, and to overlap his cheeks at opposite sides of the mouth. The film holder is also substantially subtended by the angle α. Alternatively, the film may be held in place against the patient's face as by an elastic strap wrapped around his head, or the strap may incorporate VELCRO (Registered Trade Mark) holding means. The target and shield are carried by the anode envelope 35 which is in turn carried by the tubular element 24. The anode envelope material is a low X-ray absorbtion material such as beryllium, titanium or aluminium, and forms the window for radiation emission.

Extending the description to Figure 4, the tube anode 37 is shown axially rearwardly of the gun 20*a*. The target 23, located axially rearwardly of the anode, has surfaces 23*a* and 23*b* angled rearwardly and transversely (i.e. sidewardly) relative to the axis 36. Surfaces 23*a* and 23*b* are transversely symmetrical relative to axis 36, and taper axially forwardly, as shown, at angles β relative to an upright plane 39 normal to axis 36; angle β may for example be about 20°.

In accordance with an important aspect of the invention, means is provided to effect transverse shifting of the radiation pattern produced in response to beam incidence on the target. Such means may comprise a magnet supported to be shifted transversely to deflect the beam transversely relative to the target; for example, Figure 4 shows the magnet 40 suitably supported at 41 by the tube at the right side of the axis 36, and rearwardly of the anode 37, the magnet acting to deflect the beam 21 transversely rightwardly so that it impinges on surface 23*a*. As a result, X-rays are produced to travel forwardly through the upper and lower teeth at the right side of the patient's mouth and to the film in holder 34, such teeth indicated at 44. Actually, radiation may extend transversely over the 180° angle indicated, and defined by the plane of surface 23*a*, and the shield does not interrupt such sideward radiation. See in this regard the shield openings 45 at opposite sides of the target, in Figure 6. Accordingly, the shield has sections 31*a* and 31*b* above and below the target.

Upon completion of exposure of the right side teeth 44 to X-radiation, the magnet 40 is transversely shifted to the left side of axis 36, i.e. to a position as for example appears in Figure 5. In that position, suitably supported at 41*a* by the tube, the magnet acts to deflect the beam 21 transversely leftwardly, so that it impinges on target left surface 23*b*. As a result, X-rays are produced to travel forwardly through the patient's upper and lower teeth to the left side of the mouth, and to the film in the holder 34, such teeth indicated at 44*a*. Here again, radiation may extend transversely over the 180° angle indicated and defined by the plane of surface 23*b*. The shield does not interrupt such sideward radiation, but does limit radiation in upper and lower directions, to remain within the angle α previously described.

Holders 41 and 41*a* may suitably releasably retain the magnet, as by detents. If desired, the magnet 40 may be rotatably carried to swing about axis 36 between the positions seen in Figures 4 and 5.

Figure 7 shows an alternative means to effect transverse shifting of the X-ray pattern with a fixed target, seen in FIGURE —. In this viewm the tube 12 and supported target 170 are rotatable about axis 136 between the solid line and broken line target surface positions shown at 50 and 50*a*. For example, in Figure 1 the mount 17 may incorporate means to rotatably support the tube 12 to rotate about axis 136. A sidewardly projecting handle to rotate the tube 180° outside the mouth appears at 160. A tube position locking toggle appears at 161. In target position 50, the operation corresponds to that described in Figure 4; whereas in target position 50*a*, the operation corresponds to that described in connection with Figure 5. Envelope 135 and support element 124 correspond to items 35 and 24 in Figure 2.

Figure 8 shows the modified tungsten target 70 supported by shield 71, the latter projecting forwardly at 71*a* sidewardly of the target to block X-ray sideward travel and confine same to the region 72. The latter is related to teeth 144 at one side of the mouth, as shown. Portions of the copper shield 71 not shown extend above and below the target and forwardly as in Figure 6, so that a side opening is formed at only one side of the target. Target 70 and shield 71 rotate with the tube, as explained above.

Finally, it should be pointed out that since the X-ray intensity necessary for the required film density is proportional to the square of the focus-to-film distance, the radiation output of the X-ray source at 5 cm need be only 1/25 or 4% of that required at 25 cm with the conventional extra-oral X-ray tube distance.

The wide-angle radiation pattern of the present tube can expose a panoramic view of half the mouth including upper and lower teeth in one exposure, so that only two X-ray pictures are necessary instead of 18 with conventional extra-oral tubes. When this correction 1/6 is included in the 4% noted above, the total reduction in radiation amounts to only .66% of that required with conventional dental radiography for the same visual information. This is a very

significant reduction in radiation dosage which is less than 1% of the present radiation level for whole-mouth dental radiography. In addition, the integral connection of the probe shield and target enables grounding of the target and probe for shock-proof use, and without need for coolant jacketing.

For improved image definition on the radiograph the target carrier or shield may mount a window element of X-ray transmitting material adjacent the forward face of the target for the transmission of said radiation pattern. Suitable ceramic materials are, for example, beryllium oxide and aluminum oxide optionally in admixture wit upto 20% by weight of silicon dioxide as a vitreous fluxing material.

Referring to Figure 9, it shows an unimproved means for generating an X-ray beam 80 at an elongated target region 81. X-rays 80*a* and 80*b* emanate from one end of region 81 to encompass the tooth 82 and X-rays 80*c* and 80*d* emanate from the opposite end of region 81 to encompass the tooth. The tooth boundary is not sharply delineated at the film 83, there being shadowy regions 84 and 85 at the film between rays 80*a* and 80*c*, and between rays 80*b* and 80*d*, respectively. The electron beam directed at the target is indicated at 86, within probe 87.

Figure 10 shows an improved means for generating an X-ray beam 90 at a microfocal spot at target 91. The tube means, indicated at 92, includes structure (as for example focussing anode 37) to cause the electron beam 93 to converge and form the beam impingement microfocal spot, of sufficiently small size that X-radiation 90 is directed toward the tooth 94 and film 95 to produce a sharp boundary tooth image 96 on the film. The 'spot' 91 may have an overall maximum cross-dimension of between about .05 and .10 millimeters, to produce the sharp boundary tooth image. Note the X-rays 90*a* and 90*b* encompassing the tooth and appearing to emanate from a point source at the target. A figure of merit for the reduction of geometric unsharpness U_g is directly related to focal spot size f_s and image magnification M as follows:

$$U_g = f_s (M-1)$$

where M = focus to film distance ÷ focus to subject distance.

The tube means 92 also typically includes a forming electrode 97 having a central opening 97*a* into which electron emitting filament 98 projects. The electron beam is precisely converged by the electrostatic field (see broken lines 99) produced by anode 37, and resulting in a simple convergent 'lens effect'. A high beam 'perveance' ($I = V^{3/2}$, i.e. electron flux up to 3 milleamperes, also results, with better image production at the film. The probe 100 may be narrow and hence less objectionable in a patient's mouth due to the converging of beam 93, and also due to the absence of any need for a coolant jacket about the single wall probe. A window 101 carried by the probe may consist of ceramic material, or other material, as described above, to pass the X-ray beam 90.

Figure 11 schematically shows circuit means to adjust the bias on the anode 37, and hence the electrostatic field strength and the size of spot 91; the power (KV) applied to the beam; and the operation of a microswitch which controls energisation of the X-ray tube. For example, if push-button switch 120 is operated as for example for intra-oral mode use of the probe, the bias source 121 may be energised to a level say about −50 volts appearing on lead 122 connected to electrode 37 (whereby the size of spot 91 is then about .1mm, for example); the 'power' source 123 may be energised to a level say of about 50 KV applied via lead 124 to the gun; and the position control circuit 128 of microswitch 125 is completed via lead 126. The microswitch is then activated to effect power application (see power source 155) to the X-ray tube only if the probe 100 has been rotated (see arrows) so as to direct X-ray beam toward teeth or other zones which are not 'undesired', i.e. radiation is then blocked by the shielding, as described, from passing to undesired areas of the patient's head zones.

On the other hand, if push-button switch 130 is operated, as for example for extra-oral mode use of the probe to provide dental X-rays (with film then in the patient's mouth), the bias source 121*a* may be energised to a level say of −25 volts (whereby the size of the spot is increased to about .3mm for example); the 'power' source 123*a* may be energised to a level say of about 70-90 KV; and the position control circuit 128*a* of the microswitch 125 is then deactivated, so that the X-ray tube is powered in any rotary position of the probe, as during extra-oral operation. The increased size of the spot is then no problem since the probe and target are normally located at sufficient distance from the patient's face to obviate shadowing.

Microswitch 125 may be carried by the mount 17. The probe 24 may carry a button 150 to engage and displace the microswitch element 125*a*, on rotation of the probe to the position shown.

The push-button switches 120 and 130 may be gang connected as at 140 so that closing of switch 120 opens switch 130 to deactivate sources 121*a*, 123*a* and 128*a*; and closing of switch 130 opens switch 120 to deactivate sources 121, 123 and 128. See also power sources 158 and 159. The circuitry of Figure 11 is schematic, and variations and refinements can of course be made all within the scope of the inventive intent.

It is therefore seen that provision is made to increase power to the tube and increase spot 91 size (preventing pitting or eroding of the target at high beam current densities) for extra-oral operation.

CLAIMS

1. Dental X-ray apparatus comprising an electron gun operable to provide an electron beam directed along an axis, a target carrier projecting from said gun along said axis and having a distal end of such a shape as to be receivable into the patient's mouth, a target carried by said carrier at the distal end thereof in line with said axis, and at an angle thereto which is

effective to produce a radiation pattern, when exposed to the electron beam, extending forwardly from said target towards the gun and laterally of the beam axis, and a shield of X-ray opaque material extending forwardly above and below said target and rearwardly thereof, said shield serving in use to restrict the radiation to a forwardly and/or laterally directed substantially wedge or cone-shaped pattern apexed on the target and delimited vertically substantially by the root tips of the upper and lower teeth, wherein said apparatus comprises means for focussing the electron beam into an impingement spot on said target.

2. Apparatus according to claim 1, comprising a film holder designed and mounted on said apparatus so as to be located externally of the patient's mouth, when said target carrier and target are received therein, said film holder being adapted to receive and position an unexposed X-ray film within the wedge or cone-shaped radiation pattern.

3. Apparatus according to claim 1 or 2, wherein the target comprises two substantially planar surfaces rearwardly and symmetrically inclined on opposite sides of said axis, and wherein means are provided selectively to shift the electron beam transversely to either side of said axis so as to impinge at will on one or other of said two surfaces.

4. Apparatus according to claim 3, wherein said means comprise a magnet selectively positionable on one side of the beam axis or the other.

5. Apparatus according to claim 3 or 4, wherein said surfaces are inclined at an angle of about 20° to the perpendicular to the beam axis.

6. Apparatus according to claim 1 or 2, wherein the target comprises a single substantially planar surface intersecting said beam axis but inclined at an angle thereto and means are provided selectively to rotate the target through 180° about said axis.

7. Apparatus according to claim 6, wherein the X-ray opaque shield is rotatable with said target and comprises a portion extending forwardly from the leading edge of the inclined surface of the target towards the electron gun parallel with said axis thereby substantially restricting the radiation pattern from said target to one side or other of the beam axis.

8. Apparatus according to claim 7, wherein the X-ray opaque shield comprises a blind cylinder of X-ray opaque material axially aligned on said beam axis with its open end directed towards the electron gun, said target being positioned in the bore of said cylinder adjacent the blind end, and said cylinder having longitudinally extending slot in a wall portion thereof on one side of the axis opposite the inclined surface of the target to provide a window for the passage of radiation from the target through the shield.

9. Apparatus according to claim 1 or 2, wherein the target carrier comprises a generally tubular member projecting from the electron gun coaxially along the beam axis, and positionable in use between the molars on one side of the patient's mouth, said tubular member having an end closure member with a target interiorly mounted in said tubular member adjacent said end closure member, said target having a forwardly directed surface intersecting said beam axis and inclined at an angle relative thereto, and said tubular member having at least the end portion thereof adjacent the target and extending forwardly therefrom formed of an X-ray opaque material but with a longitudinally extending window on one side of the beam axis opposite the inclined surface of the target for the passage of radiation from the target to the teeth on the opposite side of the mouth to that in which the target and target carrier are, in use, positioned.

10. Apparatus according to claim 9, wherein means are provided for selectively rotating the target and said window through 180° about said axis.

11. Apparatus according to any one of the preceding claims, comprising an element of X-ray transmitting ceramic material positioned in said shield adjacent the forward face of the target for the transmission of radiation through said shield in said wedge or coneshaped pattern.

12. Apparatus according to any one of the preceding claims, wherein said focussing means is effective to produce an impingement spot on said target having a maximum dimension in the range 0.05 to 0.10 mm.

13. Apparatus according to any one of the preceding claims, wherein focussing means is adjustable thereby selectively to vary the size of said spot.

14. Apparatus according to claim 13, wherein said focussing means include a manually operable switch having a first position in which power application to the electron gun is at a first low level, thereby producing an impingement spot of small size, and a second position in which power application to the gun is at a second and higher level, thereby to produce a larger spot.

15. Apparatus according to claim 14, comprising means to prevent power application to the gun when said switch is in said first position and said shield is out of a selected position relative to the patient's head.

16. Apparatus according to claim 1, substantially as hereinbefore described with reference to Figures 9-11 of the accompanying drawings.

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